

Adaptive Visual Tracking and Acquisition for VLC

I. ABSTRACT

OPTICAL wireless communications has brought forward a potential framework for reaching secure, high-throughput, and cost-effective wireless communications in multi-user environments [1]–[3], free space [4], [5] and underwater [6]–[8]. As the density of Internet-of-Things (IoT) devices is increasing in our living spaces, legacy radio frequency (RF) bands are getting more scarce and expensive to license. Further, due to the interference caused by the omni-directional RF signals, the aggregate wireless network throughput increases sub-linearly [9], [10], and there is an urgent need for more spatial reuse to increase the aggregate wireless network capacity.

Optical bands ($\approx 100\text{nm}$ – 1mm) are directional (i.e., amenable to high spatial reuse) and offer promising complementary wireless channels to help solve the spectrum crunch we are facing. Visible Light Communication (VLC), operating in the visible optical bands ($\approx 400\text{--}700\text{nm}$), offers great potential as it can simultaneously utilize the emerging solid-state lighting technologies and attain wireless communication as a complement to the legacy cellular RF bands. VLC can play an important role in the emerging 5G wireless systems by coexisting with Wi-Fi [11] and providing high-speed indoor access. The striking feature of this novel technology is to assure simultaneous illumination and high data rate communication without relying on additional infrastructure. In recent times, research is striving forward to incorporate this novel technology (VLC) in smart cities. The main goal of a smart city is to ensure seamless connectivity between people, government, economy, environment and to achieve efficient utilization of the resources which is indispensable for refining the quality of life and enhancing the well being of the population [12]. Further, VLC can enable localization and access applications in GPS- or RF-challenged environments such as asset tracking [13] in a hospital or inventory monitoring in a supermarket. It can also contribute to smart city applications such as road safety systems [14] and autonomous vehicles.

Compared to the legacy RF-based wireless communications, VLC has many advantages including higher bandwidth, higher potential for spatial reuse and lower probability-of-intercept. Although these features make VLC a perfect solution for high-throughput indoor wireless networking, a casual office setting involves many dynamics that may hinder the benefits of VLC. The frequent existence of mobility and undesired vibrations caused by regularities of an office setting (e.g., a simple shake from typing on a laptop or movements of smart phone while talking or watching video) may adversely affect the efficient signal reception at a VLC receiver. Such casual operation can cause attenuation and impose a time varying inter-symbol interference (ISI) on the received optical signal, and hence limit the viable communication bit rate and effective range of indoor VLC systems. This impediment hampers the widespread usage of VLC systems and necessitates intelligent tracking and acquisition algorithms for fast recovery and maintenance of VLC links. The detrimental impacts due to the above phenomena on the performance of the VLC systems and appropriate solutions have not yet been studied, which is the main focus of this work.

One current challenge facing VLC technology is the desire to operate under mobility. Due to movements of the transmitter and receiver, the light beams can get misaligned which breaks the VLC link. As a potential solution, this study introduces an adaptive tracking system that will achieve and maintain line-of-sight (LOS) between two mobile VLC receivers by using computer vision techniques. Our tracking and acquisition system utilizes optimum pattern recognition algorithms such as Bayesian classifiers to first detect the physical signature preassigned to the mobile receivers and then to extract the corresponding position information of the mobile users by high speed 60 frames per second processing of the captured image containing the physical signature of the receiver in a 2-axis Cartesian's plane. Finally, by real time estimation for the most probable position of the mobile users, the extracted information is fed back to a central Field Programmable Gate array (FPGA) to utilize and select the appropriately positioned white phosphorous LEDs.

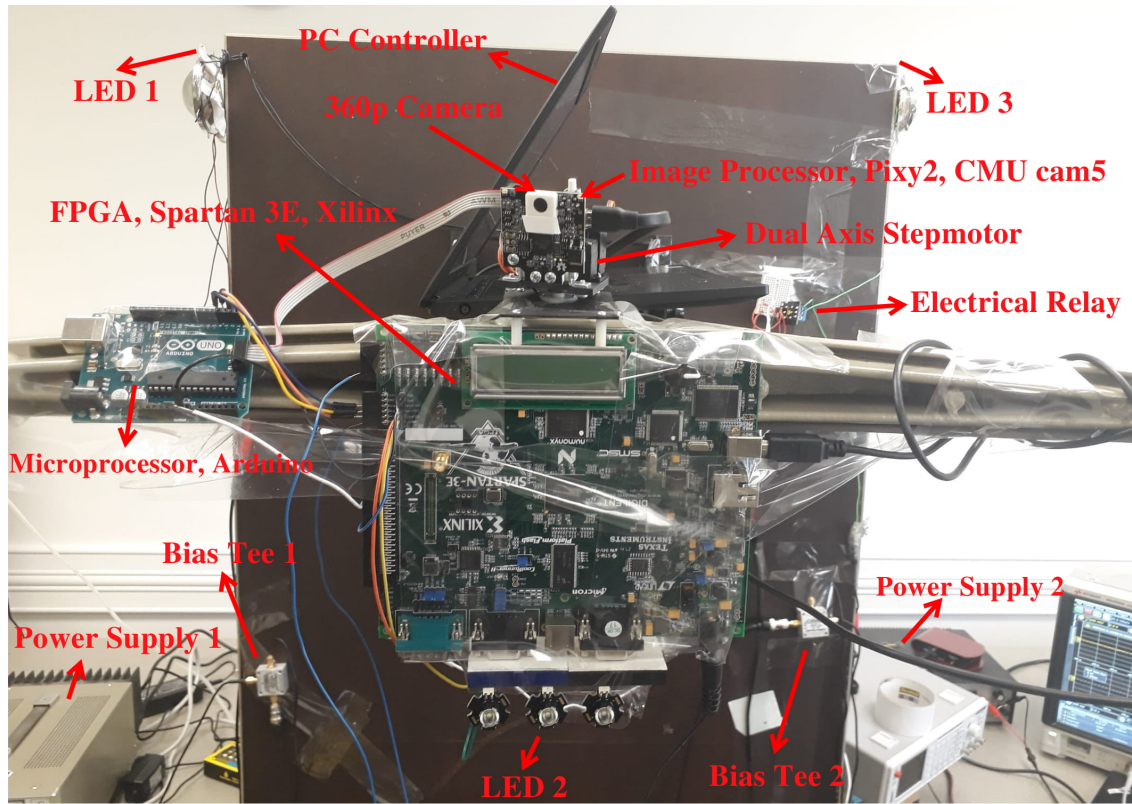


Fig. 1. Prototype of vision-based tracking and acquisition of line-of-sight discovery and maintenance of VLC links.

The proposed VLC tracking mechanism provides both optical beam steering and 360 degree capturing algorithms to provide initial acquisition, and real time tracking and maintenance of the LOS link between two transceivers, either fixed or mobile. In this paper, we further illustrate the feasibility of such systems, develop a state-of-the-art prototype and present experimental results to demonstrate the reliability and efficiency of our tracking mechanism in a mobile environment. Our prototype can be deployed in many different applications, such as reducing the time needed to achieve alignment of an indoor VLC link, and maintaining a link between a central controller and a mobile user to exchange real time video and data via high-speed VLC.

In this work, we also design and prototype a 60 Fps vision-based tracking mechanism for indoor office communications with a range of 7 m (Fig. 1). We examine the VLC link's performance and stability against mobility and vibration, to this end, we first deploy our platform in an indoor office environment link for real time data communication; and then use the eye and BER diagrams to study its performance and stability in the presence of common undesirable environmental factors such as vibration or movement of external factors (including the receiver) within the environment.

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